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Panel loudspeaker

Field of the invention ~~Technical field~~

The invention relates to panel loudspeakers and, more particularly, to improving the radiation characteristic of panel loudspeakers at low frequencies.

Background of the Invention ~~State of the art~~

Panel loudspeakers operating according to the multi-resonance principle are known in the art and frequently referred to as "distributed mode loudspeakers." These devices are essentially formed of a flat panel and at least one drive system, wherein oscillations are introduced in the panel by supplying low frequency electrical audio signals to the drive system. The drive systems for these devices are formed of one or several of electromagnetic drivers (shakers), depending on the application. However, the drive systems can also include piezo-electric bending oscillators, either alone or in combination with the aforedescribed shakers.

To properly operate panel loudspeakers, the loudspeakers are connected to a periphery using connecting elements. With this periphery, the entire panel loudspeaker can be secured from the outside and, on the other hand, the weight of the panel and of the drive system(s) can be supported in a manner advantageous for sound reproduction.

In sound reproduction systems implemented as panel loudspeakers, "bending wave radiation" can occur above a critical lower frequency limit, with the panel loudspeaker radiating the bending waves in a direction that depends on the sound frequency. A cross-section through a directional diagram shows a main lobe having a frequency dependent direction.

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The panel of the panel loudspeaker consists of a sandwich structure, wherein preferably two opposing surfaces of a very light core layer are connected, for example by an adhesive bond, by way of a respective cover layer that is thin in

comparison to the core layer. The panel loudspeaker has a particularly good sound reproduction if the material for the cover layer has a high dilatational wave velocity. Suitable material for cover layers are, for example, thin metal foils or fiber-reinforced plastic foils. The core layer also has to meet certain requirements and should have a particularly low density of, for example, 20 to 30 kg/m^3). The core layer should also be able to withstand high shearing forces acting normal to the cover layers, which requires that the elasticity module in the direction normal to the cover layers is sufficiently large, whereas a small elasticity module parallel to the cover layers is acceptable. Accordingly, the core layer can be either anisotropic or isotropic. Suitable ultra-light core layer structures are, for example, honeycomb structures made of light metal alloys or resin-impregnated fiber-reinforced paper (anisotropic) and expanded foam (isotropic).

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A system of the aforedescribed type can radiate sound waves by connecting the panel to a drive system which deforms the panel perpendicular to the plane of the cover layers in a wave-like pattern. The drive system can be a conventional magnet system that is attached to or integrated with the panel.

The efficiency of panel loudspeakers operating according to the multi-resonance principle can be optimized by leaving the marginal edge of the panel, if all possible, "unrestrained." In other words, transverse oscillations propagating in the panel should be neither restricted nor attenuated in the marginal region of the panel.

Although the panel loudspeaker described above can successfully reproduce tones in the midrange and high-frequency range, it has been observed that low frequencies, i.e., bass tones, can only be faithfully reproduced by using panels having an undesirably large surface area. If the required large surface area is not provided, then the lowest panel frequencies which support the bass reproduction, move to the mid-frequency range.

It is a therefore an object of the invention to provide panel loudspeakers with relatively small panel surface areas that have an improved sound reproduction in

the bass frequency range.

Summary ~~Description~~ of the invention

~~The object is solved by the characterizing features of claim 1. Advantageous embodiments and improvements are recited in the claims 2 to 9,~~

If a panel of a panel loudspeaker is connected with a periphery by way of connecting elements that are under mechanical tension, then additional resonances, in particular low frequency drum resonances, are produced in addition to the existing low frequency panel resonances. These additional resonances can be tuned by adjusting the tension in the connecting elements.

It should be pointed out at this point that the material used for the connecting elements and the pretension in the connecting elements has a significant impact on the reproduction of low-frequency audio signals.

It is not necessary that the tensioned connecting elements have the same tension in different directions.

If ~~according to claim 2~~ the respective connecting elements are formed either by one cover layer or by both cover layers, with the respective cover layer(s) bridging the lateral gap to the periphery, then the periphery and the panel form a very simple unit that can be manufactured easily and inexpensively.

If ~~according to claim 3~~ the respective periphery is formed by a frame, then such assemblies can be easily connected with other objects, because the required tension in the cover layer(s) and/or the connecting elements can be produced with high quality already at the place of manufacture.

The panel loudspeakers according to the invention can not only be used as stand-alone sound reproduction units. Instead or in addition, ~~according to claim 4~~ several panel loudspeakers can also be combined into a larger acoustic wall, without the need to directly connect the individual panel with a periphery that is not excited by drivers. It has been observed in the context of the present

invention that the same type of connecting elements that are employed to connect the panel to a periphery that is not excited (e.g., a frame), can also be used to connect adjacent panels of a larger acoustic wall with one another, without acoustically coupling these panels. If such larger acoustic wall ~~– as already described in connection with claim 1 –~~ is also connected, for example, with a frame through corresponding connecting elements, then the tension that exists in the connecting elements attached to the frame can also be used to adjust the tension in the connecting elements that are disposed between the panels of the acoustic wall. The tension in the connection between two adjacent decoupled panels can then be fine-tuned by selecting a proper size and/or material for the respective connecting element.

The ~~According to claim 5, the~~ tension in the cover layers and/or connecting elements can be easily adjusted by providing tensioning strips on the edges of the corresponding connecting elements that are connected with the periphery. The tension can further be adjusted by providing the periphery with edges which are in contact with the tensioning strips when the panel is connected to the periphery, and by making the distance between the tensioning strips and the coordinate lines extending through the center of the respective panel loudspeaker smaller than the distance between the edges and the coordinate lines that also extend through the center of the periphery, before the panel is connected to the periphery. By connecting the tensioning strips with the edges, a uniform tension defined by the respective distances can be easily attained in the cover layers and the connecting elements of the respective panel loudspeaker.

The connecting elements under tension provide particularly advantageous sound reproduction conditions with a panel loudspeaker formed in this manner and used for reproducing low-frequency audio signals. However, the application of pretensioned connecting elements is not limited to improving only the bass reproduction. Cover layers and/or connecting elements under tension can also be employed with midrange and broadband panels.

If ~~, according to claim 7,~~ the regions of the cover layers that are connected with the core layer are ~~also~~ under mechanical tension, then the dilatational wave velocity of the cover layers is increased, in particular when using thin metal foils.

The ~~According to claim 8, the~~ oscillation amplitude of the very low-frequency resonances produced by the mechanical tension of the connecting elements and/or the cover layers can be reduced by providing those elements that are subject to mechanical tension (cover layers and/or connecting elements) with attenuation (damping) elements to provide damping.

The ~~According to claim 9, the~~ mechanical tension in the connecting elements and the cover layers can be different. In this way, different attenuation values can be easily realized for the different elements.

Brief description of the drawings

Fig. 1 shows a top view of a panel loudspeaker;

Fig. 2 shows a top view of another panel loudspeaker;

Fig. 3 is a side view of the panel loudspeaker of Fig. 1;

Fig. 4a, b show another side view of a panel loudspeaker; and

Fig. 5a, b show another side view of a panel loudspeaker.

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The invention will now be described in detail with reference to the Figures. Fig. 1 shows a sound reproduction device 10 in form of a panel loudspeaker ~~11~~ operating according to the aforedescribed "bending wave principle." The sound reproduction device 10 is formed by a panel 11 and a periphery 12.

As seen in more detail in Fig. 3, the panel 11 is constructed as a sandwich structure which includes a core layer 13, which in the present example has a honeycomb structure, and thin cover layers 14.o, 14.u disposed on two opposing

surfaces of the core layer 13.

In the embodiment depicted in Fig. 1, the periphery 12 is formed by an installation wall with an opening 15. The panel 11 is inserted into this opening. The connection between the panel 11 and the periphery 12 formed by the installation wall 16 is implemented by connecting a connecting element 17 with the cover layers 14.o and the installation wall 16. As seen from Fig. 1, which depicts a top view of a panel loudspeaker 10, the connecting element 17 is formed as a single piece and completely covers the gap A formed between the opposing edges 24 and 24' of the panel 11 and the respective opening 15.

Excellent sound reproduction is achieved by placing the cover layers 14.o, 14.u of the panel 11 under mechanical tension. The tension in the connecting elements 17 which is indicated in Fig. 3 by the double arrow P, is achieved in the embodiment illustrated in Fig. 1 by stretching the regions of the connecting element 17 that are in contact with the installation wall 16, in the x- and y-direction (Fig. 1) after the panel 11 is inserted in the opening 15, but before these regions are connected with the installation wall 16.

For sake of completeness, it should be mentioned with reference to Figs. 1 and 3, that the reference numeral 18 in Fig. 1 indicates drivers that introduce oscillations in the panel 11, and that the connecting element 17" indicated in Fig. 3 by the dashed line can provide another connection - which is also under tension - between the installation wall 16 and the panel 11.

As indicated in Fig. 3 by the dotted double arrows P4, the cover layers 14.u, 14.o that are connected with the core layer 13 can also be under mechanical tension. However, the degree of the mechanical tension of the connecting elements 17 and the cover layers 14.u, 14.o need in this case not be identical. The reference numerals 30 in Fig. 3 indicate optional damping element s for limiting the oscillation amplitude when the connecting elements 17,17' and/or the cover layers 14.o, 14.u are under mechanical tension.

Fig. 2 shows a panel loudspeaker 10 consisting of several panels 11. The panels 11" surrounding the panel 11' form the periphery ~~11'~~ of the panel 11' with respect to the center panel 11'. In the illustrated embodiment, a separate frame that surrounds all panels 11 forms the periphery 12 for all panels. Using a separate frame 19 with one or several panels 11 has the advantage that the connecting elements 17 do not have to be tensioned when the panel(s) is/are connected at the installation location, but that the tension in the connecting elements 17 can be adjusted easily and exactly already at the factory, if the respective panel loudspeaker(s) is/are shipped installed in a frame 19.

As also seen from the top view of Fig. 2, the panels 11 can have different dimensions as well as a different spacing from one another and/or from the frame 19. The panels 11 have different dimensions because the different panels 11 of the device illustrated in Fig. 2 are so-called range radiators optimized for different audio frequency ranges. For decoupling the different panels 11 from each other, the spacing between the individual panels 11 and/or the spacing between the panels 11 and the frame 19 is also adapted to the respective reproduction range of these panels 11. Since the panels 11 are optimized for different frequency ranges, the mechanical tension in the cover layers (not shown in detail in Fig. 2) of the different panels 11 can also be adapted to the different reproduction requirements.

In the embodiment depicted in Fig. 2, separate connecting elements 17 are no longer required. Instead, the panels 11 are connected with each other and/or with the frame 19 only through the cover layer 14.o. This type of connection is shown in detail in Figs. 4b and 5b and will be discussed below more specifically with reference to these Figures.

Fig. 4a depicts an embodiment of a frame 19. A panel 11 is arranged above the frame 19. Unlike the panel 11 shown in Fig. 3, the cover layer projects slightly over the marginal edges 24 of the core layer 13. In addition, tension strips 20 are attached to the marginal edges 24" of the cover layer 14.o. If the cover layer

14.o is elastically deformed by an external force in the direction of the arrow P1 and is in this state lowered towards the frame 19 in the direction P2, then the situation shown in Fig. 4b will arise where the cover layer 14.o contacts the frame. As also seen in Fig. 4b, the panel 11 is connected to the frame 19 only through the cover layer 14.o and the tension strips 20 contact the lateral edges 21 of the frame at the end of the aforedescribed movement in the direction of the arrow P2. Since according to the situation illustrated in Fig. 4a, the separation A' between the two tension strips 20 before ~~after~~ installation is smaller than the separation A" between two opposing marginal edges 21 of the frame 19, the desired mechanical tension (as indicated by the double arrows) builds up in the situation depicted in Fig. 4b as a result of the restoring forces produced in the regions 17' of the cover layer 14.o.

If, unlike the illustration of Figs. 4a and 4b, the cover layer 14.o is not connected with the core layer 13, then tension builds up in the entire cover layer 14.o. To maintain the advantageous effects of the tension cover layer 14.o for sound transmission, the core layer 13 will have to be connected with the cover layer 14.o.

Figs. 5a and 5b depict another embodiment of a connection under mechanical tension between a panel 11 and a frame 19 after installation. Unlike the embodiment depicted in Figs. 4a and 4b, the spacing A' between the tension strips 20 is identical to the spacing A" between the opposing marginal edges 21 of the frame 19. With these values for the respective spacing, the cover layer 14.o depicted in Fig. 5a need not be exposed to a force (P1) (shown in Fig. 4a) in order to establish a connection with a frame 19 (Fig. 5b). The required tension in the regions 17' of the cover layer 14.o is produced by first establishing contact between the cover layer 14.o and the frame 19 as well as between the tension strips 20 and the marginal edges 21 without tension (a shown on the left side in Fig. 5b), and by subsequently rotating one or both tension strips 20 in the direction of arrow P3. As a result, the narrow side 23 of the tension strips 20 - instead of the longer side 22 - makes contact with the marginal edge 21 of the frame 19 (a shown on the

right side in Fig. 5b).

If tension is to be introduced not only in the regions 17' of the cover layer 14.o, but rather across the entire cover layer 14.o, then the cover layer 14.o should be connected to the frame 19 following the discussion above with reference to Figs. 4a to 5b, whereafter the core layer 13 is attached to the fully tensioned cover layer 14.o ~~14.o,~~ for example, with an adhesive. If the entire cover layer 14.o is under tension, then the core layer 13 and the cover layer 14.o need not be connected in a subsequent separate operation as long as the unit composed of the core layer 13 and the cover layer 14.o is connected according to Figs. 4a to 5b and the adhesive connecting the cover layer 14.o with the core layer 13 has not yet set.

For sake of completeness, it should be noted that the embodiments depicted in Figs. 4a to 5b can be modified so as to place both cover layers 14.o and 14.u under mechanical tension.